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Task I

"Electron Time-of-Flight Spectroscopy in the 1 to 1/100 eV Energy Range"

This work is aimed at measuring collision cross sections of electrons in the milli-electron-volt (meV) energy range with various atoms and molecules. In this energy range, high resolution measurements of all kinds of cross sections, total and differential, elastic and inelastic, are needed for checking interaction theories and for improving the understanding of complicated systems like the earth's ionosphere.

Electron time-of-flight spectroscopy was proposed here as a method for achieving a high energy resolution in the planned cross section measurements. Numerical feasibility studies indicated that the technique proposed will yield a better energy resolution than the existing electron spectrometers and still provide an intensity sufficiently high for obtaining a good statistical accuracy. A design study for a time-of-flight monochromator is given in the appendix.

However, before one can attempt to do anything with meV electrons, a vacuum system of extreme cleanliness and a good magnetic shielding arrangement, producing residual magnetic fields smaller than 10^{-4} gauss, have to be provided. The design and building of such a vacuum system and magnetic shielding arrangement were accomplished during the report period. The system developed consists of an electron-optical bench in a cylindrical ultra-high vacuum

chamber. It is supported and pumped on one end from the main vacuum chamber which carries all the flanges for electrical feed-throughs and vacuum gauges. The magnetic shielding of the bench region is provided by two external co-axial cylinders. The major vacuum components are ready for assembling. The main chamber was built from no. 316 stainless steel. The ferromagnetism, introduced by machining and welding, was completely eliminated by annealing. The magnetic shielding cylinders were built after the design parameters had been determined by means of a computer calculation. The cylindrical vacuum chamber and the support framework for the electron-optical bench are being built. Right now we are designing the first electron optical components and we hope to start testing within the next months.

Appendix to Semi-Annual Report of Task I

"Design Study for a Time-of-Flight Monochromator"

In order to show the feasibility of the proposed technique we will briefly discuss the relevant theoretical relations and give some numerical values for the parameters of a monochromator yielding electrons with 1 meV energy spread.

Gating

Consider a parallel electron beam of width, w, and voltage, V_g. This beam is deflected by a transverse magnetic field, B, confined to a region of diameter, d. The beam is swept across an

aperture of diameter, a, at a distance, L, from the field region. Assuming that w << d << L, the time during which electrons are transmitted by the gate, Δt, follows as

$$\Delta t = \sqrt{\frac{2}{e/m}} \quad \frac{a}{d \cdot L} \quad \frac{\sqrt{V_g}}{dB/dt} \tag{1}$$

In reality the beam has a finite plane aperture angle, α_g, and a finite radius of the source image, r_g, and the sweep field is placed near the principal plane of a lens which images the beam onto the aperture. Under these conditions we can replace beam width, w, and aperture, a, by

$$a = 2r_g, \quad w = 2\alpha_g \cdot L. \tag{2}$$

The changing magnetic field causes an induced electric field which affects the energy distribution in an electron beam of finite width. The total beam voltage spread, resulting from the magnetic gating, is given by

$$\Delta V_g = w \cdot d \times \frac{dB}{dt} \tag{3}$$

and by combining Eqs. 1 to 3 we obtain

$$\Delta t = \frac{4\sqrt{2}}{\sqrt{e/m}} \quad r_g \alpha_g \sqrt{V_g} \times \frac{1}{\Delta V_g} \tag{4}$$

Sweeping the beam by means of a transverse <u>electric</u> field causes a voltage spread due to the time-varying potential in the field region. The resulting relation is identical to Eq. 4.

Geometric Electron Optics

The electron beam, which has a voltage, V_g, while being gated, passes through the drift chamber with the lower beam voltage, V_d. From the Helmholtz law it follows that

$$r_g \alpha_g \sqrt{V_g} = r_d \alpha_d \sqrt{V_d}, \tag{5}$$

where r_d is the image radius and α_d is the aperture angle in the drift chamber.

Geometric differences in path length will lead to flight time differences, $\Delta\tau \simeq \alpha_d^2 T$, (6)

where T is the total flight time.

Energy Resolution

If $V_d \ll V_g$, the total flight time, T, between gates I and II is almost entirely given by the time the electrons spend in the drift chamber. Thus with a drift chamber length, Λ, we get approximately

$$T = \frac{\Lambda}{\sqrt{2e/m\ V_d}} . \tag{7}$$

Assuming that the two gates transmit during time intervals of equal length, Δt, the final beam voltage spread, ΔV_f, follows as

$$\Delta V_f = 2 \frac{\Delta t}{T} V_d \tag{8}$$

Space Charge

The space-charge limited intensity of an electron beam is proportional to $\alpha^2 \cdot V^{3/2}$, where α is the plane aperture angle and V is the electron voltage. The intensity limiting place of the monochromator is the entrance of the drift chamber where the elec-

trons are slow but have not spread out in space yet. In our case the maximum intensity can be written as

$$I = 2.4 \times 10^{14} \frac{\text{electrons}}{\text{sec.(volt)}^{3/2}} \times \alpha_d^2 V_d^{3/2} \times f \frac{\Delta V_f}{\Delta V} \; b \qquad (9)$$

where f is the duty factor, maximally $f = \Delta t/T$, ΔV_i is the voltage spread in the initial beam, $\Delta V_f/\Delta V_i$ describes approximately the intensity loss due to monochromatization, and b stands for the intensity increase achievable by means of velocity bunching. Substituting

$$f = \frac{1}{2} \Delta V_f / V_d$$

we get

$$I = 1.2 \times 10^{14} \frac{\text{electrons}}{\text{sec.(volt)}^{3/2}} \; \alpha_d^2 \; V_d^{1/2} \; \frac{(\Delta V_f)^2}{\Delta V_i} \; b. \qquad (10)$$

For very low voltages, $V_d \lesssim \Delta V_i$, this relation cannot be expected to hold exactly, however, it will give an estimate on the order of magnitude.

Choosing the Design Parameters

Starting with a certain desired value of ΔV_f and requesting that $\Delta V_g \lesssim \Delta V_f$, we can obtain an upper limit for the drift-chamber voltage by combining Eq.'s 4, 5, 7, 8:

$$V_d \lesssim \frac{1}{4} \Delta V_f \cdot \sqrt{\frac{\Lambda}{r_d \alpha_d}} \; . \qquad (11)$$

For maximum intensity, α_d should be made as big as technically possible (Eq. 9), provided $\Delta\tau < \Delta t$ (Eq. 6) is satisfied. For counting purposes a high repetition rate is desired which calls for a high drift-chamber voltage, V_d, within the limits of condition (11). A value for the gating voltage, V_g, can be chosen in accor-

dance with Eq. 5. Numerical values for an example are given in Table I.

Table I

Design Parameters for a 1-meV Time-of-Flight Monochromator

Desired final energy spread ($e \cdot \Delta V_f$)	1 meV
Length of drift chamber (Λ)	10 cm
Image radius in drift chamber (r_d)	0.5 mm
Aperture angle in drift chamber (α_d)	0.1 rad
Electron energy in drift chamber ($e \cdot V_d$)	10 meV
Flight time through drift chamber (T)	1.7 μsec
Gating pulse length (Δt)	80 nsec
Beam energy at gates ($e \cdot V_g$)	10 eV
Image radius in gating region (r_g)	0.5 mm
Aperture angle in gating region (α_g)	.3 mrad
Distance between sweep field and aperture (L)	10 cm
Flight time through one gate	54 nsec
Total flight time from gate to gate	~2 μsec
Maximum repetition rate	500 kHz
Duty factor of monochromator	4.10^{-2}
Maximal intensity without velocity bunching ($\Delta V_i \simeq 0.2$ volt)	$\sim 5 \cdot 10^5$ electrons /sec =1 electron/pulse

Velocity bunching can be accomplished by placing an electrode with time-varying potential at the exit end of the drift chamber. This electrode potential has to change in time such that the fast electrons (arriving early) will be decelerated and the slow electrons (arriving late) will be accelerated. With a simple linear time variation ("saw-tooth voltage"), an intensity increase of a factor of ten might be possible.

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"Research on Dissociation of Molecular Hydrogen Leading to Formation of Metastable Hydrogen Atoms."

TASK II

In the first six months we have made progress on short-term and long-term goals.

The short term goal has been to put together again, without modification, the original version of the apparatus (Leventhal, Robiscoe and Lea, Phys. Rev. 158, 49, 1967). The long-term goal has been the preparation of a "Mk II" version of the apparatus, incorporating major alterations and improvements.

Progress on the short-term goal has been impeded by the unavailability of certain items of equipment originally used. This has been overcome by use of borrowed equipment, but lack of compatibility of some of this has necessitated further construction. On this account, the short term objective has not yet been achieved.

The Mk II version of the apparatus will employ better vacuum techniques. Mercury vapor diffusion pumping has been selected, and a 9 inch pump and associated vacuum hardware has been ordered from Edwards High Vacuum. Some of this equipment has already been received. The decision on whether to purchase a multichannel pulse height analyser or to invest in a small computer for data acquisition is still pending. Other electronic items (power supplies, pulse handling circuitry) have either been ordered or shortly will be.

A consideration of the operating parameters of the Mk I version of the apparatus has allowed an order of magnitude estimate of the cross section for the process

$$e + H_2 \rightarrow e + H(2s) + H(1s)$$

We obtain $\sigma = 10^{-20}$ cm^2 for electron energies of 30 volts. By way of comparison, this result is two orders of magnitude smaller than the figure quoted by Lichten and Schultz. The reduced apparent cross section may be due to loss of slow ($< 4 \times 10^5$ cm/sec) metastable atoms between source and detector, a possibility which had been discounted in the earlier work. However, a deficiency in numbers of slow metastable atoms as compared with theoretical predictions due to Harriman had been noted. This, then, is one further aspect of the experiment worthy of careful investigation.

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"Electron Energy Losses in Molecular Gases at Low Energy"

Task III

During the past six months we have designed and built the vacuum system and the gas-handling system necessary for the operation of the experiment. Also we have put into operation a tube which will be used for study of the low energy inelastic cross sections near threshold.

The tube consists of a thoria-coated iridium filament which emits electrons. The electrons, aligned by magnetic field of about 200 Gauss, traverse a number of electrodes which are used to cut the electron energy distribution of the electrons in such a manner that we can study the effect of essentially mono-energetic electrons. The electrons enter a collision chamber in which a potential well is established with respect to the end walls and the axial grid. The electrons then pass out of the collision chamber to an electron collector. When an inelastic process takes place in the collision chamber, the electrons lose the appropriate amount of energy, and because of the existence of the potential well, the electrons are trapped in the collision chamber. They oscillate back and forth in the axial magnetic field until, by multiple collisions, they diffuse out of the collision chamber to an axial cylindrical collector. At this collector the electron current is measured and a signal at the collector is an indication that an inelastic process has taken place in the collision chamber. Every inelastic process leads to a detected signal regardless of the nature of the state that is excited. Thus we can plot out, if we wish, the excitation spectrum of any atom or molecule under study and obtain cross sections. One of the

limitations of the method is the fact that at extremely low energies around zero eV, trapped electrons can also be produced by elastic scattering, because in an elastic collision the velocity vector is re-oriented and electrons scattered around 90^{o} are prevented from reaching the electron collector and reach the collector of trapped electrons instead. This is a bothersome fact when we investigate energy loss processes in the energy region from 0 - 1 eV. At the present time we are studying this "trapping" of elastically scattered electrons in order to give us a clearer view of the interference of this effect with the study of the vibrational excitation of molecules. We are performing this study in H_2 gas because H_2 has a vibrational quantum of .53 eV, i.e., it is the largest vibrational quantum of any diatomic gas.

Our equipment is now completely set up in the renovated Mason Laboratory, and the vacuum system, electronic components and gas handling seem to work well.

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13. ABSTRACT

Task I: "Electron Time-of-Flight Spectroscopy in the 1 to 1/100 eV Energy Range"

Task II: "Research on Dissociation of Molecular Hydrogen Leading to Formation of Metastable Hydrogen Atoms."

Task III: "Electron Energy Losses in Molecular Gases at Low Energy"

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